THE DEVELOPMENT OF AN EVALUATION FRAMEWORK BASED ON THE DESIGN SCIENCE APPROACH

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ABSTRACT

This paper is part of an on going research work focusing on the development and evaluation of a visual management method, known as LCM[4], using design science research. LCM is a visual management method, developed initially by the researcher in 2007 in practice to address a practical problem faced on a construction site. This practical problem was a lack of transparency in daily operations onsite, which led to difficulties in communication, decision-making and general progress in daily work (Brady, et al 2012). LCM also addresses a theoretical problem which is the lack of broader, holistic solutions when implementing Lean and Visual Management (Picchi, 2004, Tezel, 2011). By applying various visual tools together in a unique way, a structure is provided to visually plan and manage the construction process, bringing clarity, aiding communication and collaboration, decision-making and simplifying information. LCM's main aims are to improve transparency in the overall construction process, implement a visualised flow and a pull system in the daily planning of work onsite and to provide a mechanism for regular quality checks and continuous improvement. Part of the evaluation will be to compare LCM to other planning and control systems such as Last Planner in order to clarify the similarities and differences and also its contribution to knowledge. The overall aim of the paper is to describe and present the development of a suitable framework which is used to evaluate this method within the context of Design Science. Findings from an analysis on the method are presented which specifies its outcomes according to this methodology. Evaluation criteria that make up the framework are identified based on the Design Science literature and the aims of the LCM method itself and are applied in a focused way to the constructs, models, methods and instantiations of LCM.

KEYWORDS

Design Science, Visual Management, Production planning, Control.

INTRODUCTION

The LCM method was first developed in 2007 in practice to address a practical problem faced on a construction site. This practical problem was defined as a lack of transparency in daily operations onsite, the symptoms being difficulties in

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4 LCM is an acronymn for Lean Construction Management in practice

communication, decision-making and an inability to effectively manage work onsite on a day to day basis. A direct result of these symptoms was a construction process that was not carried out according to plan, bottle neck areas where companies prevented each other from working while other areas remained vacant, damaged or missing material and overall, a process that created a high level of waste in daily operations. LCM also addresses a theoretical problem which is a call for broader, holistic solutions when implementing Lean and Visual Management: "when tools are implemented in isolation, poor implementations of lean concepts are observed (Picchi, et al 2004)". The use of lean tools based on a broader lean system analysis is necessary to achieve more significant results (Womack and Jones 1996; Liker 1997; Rother and Shook 2000). Picchi, et al 2004, proposed a framework for such broader solutions based on the five lean principles: value, value stream, flow, pull and perfection. In this work, scenarios were presented as to how a wider application of lean thinking can be applied to job sites and it was determined that no such implementations exist, which presented a challenge for future research and practical implementations. To understand the nature of the artifact that will be evaluated, it is necessary to first analyse LCM according to the outcomes of Design Science: constructs, models, methods and instantiations (see Table 1 and Table 2 below). This is an important step in the evaluation, to fully understand the artifact and its functions and to able to apply the evaluation criteria in a focused way to the individual outcomes. Since the first development of LCM as part of this research work, the method has been applied and adapted by third parties to over 20 different construction projects ranging from petrochemical plants, power plants, refurbishments, new construction and other housing projects. An important part of this overall research is to evaluate the method based on both the researchers' first development case study (internal evaluation) and also on some of the more recent applications mentioned above (external evaluation). An individual framework suitable to evaluate LCM however does not exist. Rather, the literature describes certain key factors to be considered when carrying out an evaluation, within the context of Design Science. On review of the literature on Design Science, evaluation criteria such as the usefulness and effectiveness of the LCM method in practice were found to be important. Other criteria such as the applicability of LCM to various different types of construction projects and the theoretical significance of this method for the area of visual management were also deemed important for the framework.

EVALUATION FRAMEWORK

Design Science is a research method for producing innovative constructions, intended to solve problems faced in the real world and, by that means, to make a contribution to the theory of the discipline in which it is applied (Lukka, 2003). Design Science products can be of four types (March and Smith, 1995): constructs, models, methods and instantiations. Rather than posing theories, design scientists strive to create models, methods and instantiations that are innovative and valuable to both theory development and improvement to practice. Design Science consists of two basic activities: build and evaluate (March, et Al 1995). Building is the process of constructing an artefact for a specific purpose and evaluation, being at the heart of the design science approach, is the process of determining how well the artefact performs. Design Science was chosen for this research because it involves the development of a solution that has practical and theoretical relevance. Design Science is also a suitable strategy for this work since LCM was developed initially in response to a practical problem which is being more formally developed through this research work. As part of this formalisation, this paper proposes a framework to be applied to the LCM method that includes important evaluation criteria from the Design Science literature.

INTERNAL AND EXTERNAL EVALUATION

The evaluation is carried out in cycles or loops that form part of an internal and external evaluation. The idea that the research process can be carried out in „loops", is underlined in the literature. These loops are referred to by Vaishnavi and Kuechler (2007), as circumscriptions and involve gaining an understanding that is only achieved by the specific act of creating an artefact. Circumscriptions can occur at the development and evaluation steps and lead to a revision of the problem awareness, creating a new cycle of design construction (Vaishnavi and Kuechler, 2007). The internal evaluation (first loop) is based on the first original development of LCM in practice by the researcher (see Figure 1 below). Here an instantiation is created and the researcher reflects upon the solution and the instantiation (this evaluation is the first step towards formalising the model from a theoretical side). The internal testing as part of the internal evaluation is also referred to by, Van Aken, 2004, as α-testing ie: the analysis of the effectiveness of a certain rule in the original context. Lukka (2000) emphasises that an important step in the Design Science approach is not only the testing of a construction in a "technical" manner but also the "running" of the process, should be tested as a whole. Typically according to Lukka (2000), the innovation has to be "sold" to the target organisation, accompanied with an adequate instruction manual, training of personnel and potential pilot tests. Building on this, Lukka (2000) also emphasises that it is important then to "Ponder the scope of applicability of the solution". According to Henver, et Al, it is inherently iterative and incremental (Hevner et al*.,* 2004): the testing step provides essential feedback for the construction step in terms of the quality of the development process and the solution itself. In fact, the application and test of a solution precede its complete development because only through its study and use it is possible to formalise the models, constructs, and methods on which it is based (March and Smith, 1995). This thinking is also part of the hermeneutic cycle, where one's understanding of the text as a whole is established by reference to the individual parts and one's understanding of each individual part by reference to the whole. The second loop is part of the external evaluation and focuses on an evaluation of the method as it has been applied and adapted by third parties. In the literature this type of evaluation is referred to as β-testing (Van Aken, 2004) i.e.: translating the rule to other contexts, having third parties use it, access its effectiveness and make final improvements. In the case of LCM, its further application and adaptation to different construction scenarios in practice provides a rich source of data for reflection on implementation and any further improvements of the original method that have already taken effect. According to Lukka 2002, this loop requires the ability of the researcher to step back from the empirical work, control his or her level of commitment and start pondering the learning process he or she has gone through, together with the target organisation. The key question here according to Lukka 2000, is to analyse the results of the process and its preconditions. "To what extent and with what case by case modifications is the construction transferable to other organisations "(Lukka, 2000). This is an important focus of the external evaluation as part of the research work. The researcher takes a step back from the initial development of LCM and observes how it has been adapted and modified to different project situations (in which the researcher was not directly involved). Indeed, the idea of learning loops or cycles is also common to action research, Kolbs active learning approach and the QM Shewart / Deming cycle. An important outcome of the internal and external evaluation is to establish whether a real-world problem has been solved (and to what extent) by the implementation of a new construction and what are the practical and theoretical contributions of this solution.

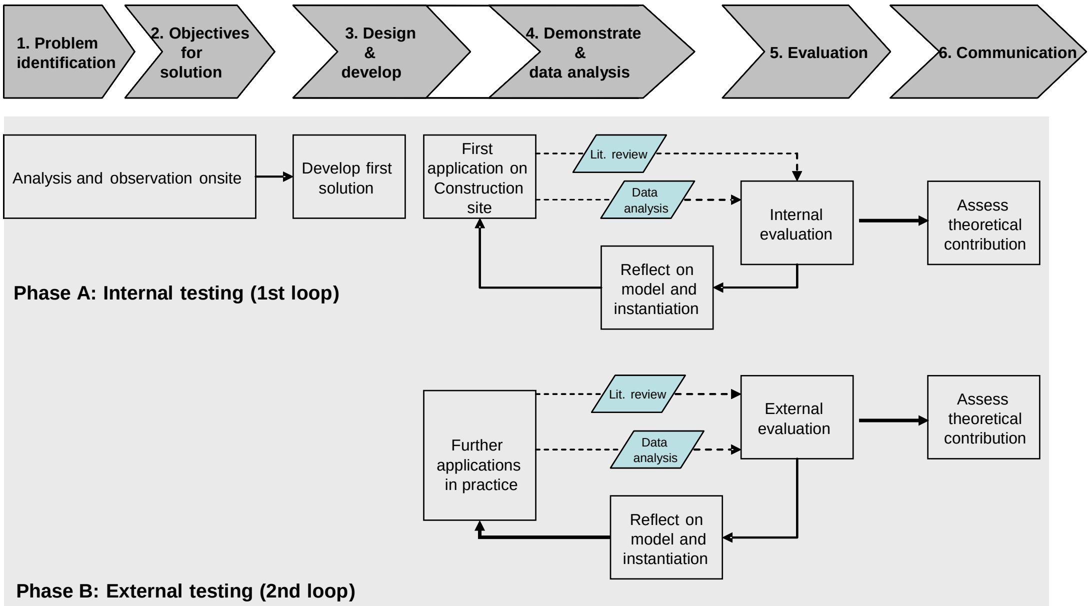

Figure 1: Design Science research process based on 6 steps as proposed by Pfeffers, et al 2007.

LCM OUTCOMES ACCORDING TO DESIGN SCIENCE

As mentioned above, as part of the evaluation process within the Design Science approach, it is important to first of all identify the outcomes of Design Science to understand the individual parts of the artefact and its functions, so that the evaluation criteria can be applied to each part accordingly. March et al (1995) classifies the four outputs of Design Science as: a construct, model, method or instantiation and suggests ways to evaluate these outputs. Table 1 below summarises these definitions and highlights the evaluation criteria deemed important when evaluating the different outcomes of design science

Table 1: Evaluation criteria for outcomes of Design Science

Design Science output	Definition	Important evaluation criteria (March et al, 1995)*
Construct*	a conceptualisation used to describe problems and specify solutions eg can be formal (data modelling) or informal (cooperative work)	Completeness, simplicity, elegance and easy of use
Model*	a set of propositions or statements expressing relationships among constructs. A description of how things are.	fidelity with real world phenomena, completeness , level of detail, robustness and internal consistency
Method*	a set of steps used to perform a task. They are based on a set of underlying constructs (language) and parts of the model as input.	operationality (the ability to perform the intended task or the ability of humans to effectively use the method if it is not algorithmic), effeciency, generality and ease of use.
Instant-iation*	is the realisation of the artifact in its environment	Does it work and how well does it work? Why did it work and why did it not work? Efficiency and effectiveness of the artifact and its impact on its environment and its users.

As is shown in table 1, March et al 1995, defines the four outcomes of design science and the relationship between each as follows: a construct or concepts form the vocabulary of a domain. They constitute a conceptualisation used to describe problems within the domain and to specify their solutions. Such constructs may be highly formalised as in semantic data modelling formalisms (having constructs such as entities, attributes, relationships, identifiers, constraints (Hull, et al 1987) or informal as in cooperative work (consensus, participation, satisfaction (Kraemer, et al 1988). A model is a set of propositions or statements expressing relationships among constructs. A model can be viewed as either a description or a prescription, that is, as a representation of how things are, or a statement of how things should be. A method is a set of steps (an algorithm or guideline) used to perform a task. Methods are based on a set of underlying constructs (language) and a representation (model) of the solution space (March, et al 1995). Methods can be tied to particular models in that the steps take parts of the model as input. Furthermore, methods are often used to translate from one model or representation to another in the course of solving a problem. An instantiation is the realisation of an artefact in its environment. Instantiations operationalise constructs, models, and methods. However, an instantiation may actually precede the complete articulation of its underlying constructs, models, and methods. There is some ambiguity whether all or just some of these outcomes must be considered in a design science report, but in the case of this research, instantiations will be evaluated which means all four aspects should be considered.

An overview of the constructs, models and methods of the visual management method LCM can be seen in the table 2 and figures 2 and 3 below. The constructs of the LCM method are based initially on the idea behind the Lean principles of Value, Value Stream, Flow, Pull and Perfection (Womack, et al 1996) and a need to improve transparency onsite. LCM provides a structure to implement flow and pull in the construction process in a visual way which brings clarity, aids communication, decision-making and encourages continuous improvement. The principle of Value is the starting point to the application of Lean Thinking: focusing on the whole process and determining the main characteristics of a product and what a customer is willing to pay for. This is also a first step in the identification of waste in the process. The second principle is that of the Value Stream: understanding the physical flows of material, people and information. The principle of Flow is concerned with the optimal flow of process activities by eliminating waste and reducing lead-time (Womack and Jones, 1996). Pull (together with Flow) are regarded as the core characteristics of Lean Thinking and cornerstones for the elimination of waste. The idea of pull is to produce only as much as the proceeding work activity needs while keeping inventory at a minimum. The principle of perfection is closely related to the idea of continuous improvement –constantly striving for perfection in processes. The constructs and models that support the instantiations are illustrated in table 2 and figure 2 below. A total of 16 different models make up the LCM method. The LCM method itself is also a model which shows how all of these individual ones are co-ordinated and implemented together. The overall process map, process planning tool, actions lists and metric for stability are models whose make up can be traced back to the constructs Value and Value stream. Also in table 2, the constructs Flow and Pull are linked to the following LCM models: planning boards, construction cards, problems cards, logistic board, logistic cards, visualised site layout and material database. The LCM models of actions plans, metrics and colour-coded card visualisation are based on the construct of perfection. Figure 2 illustrates all models to be found in the LCM method. It highlights the ideas behind these models and also how the LCM method can be validated: i.e. through the measurement of process stability, quality, on-time delivery and lead-time.

Table 2: LCM outputs according to Design Science

	TRANSPARENCY													
	VALUE & VALUE STREAM				FLOW & PULL						PERFECTION			
CONSTRUCT	Optimised construction process	Identify & remove constraints	Common understanding of overall process	Measurement of process stability	Visualise and allign daily work (pull)	Easy identification of vacant areas	Clearly define & visualise daily work packages	Visualisation of constraints	Visualisation and optimisation of logistic resources (third party development)	Optimised organisation of material onsite	Daily quality checks	Documentation and tracking of constraint removal	Measurement of completeness of daily work	Measurement of quality
MODEL (LCM specific)	1. Overall process analysis			5.SPP (stability of process planning) metric (further development in practice by third party)	6.Planning board		7.Construction cards for each company	8.Problem cards	9.Logistic board	11.Visualised, colour-coded site layout	13.Complete cards visualised on "apartment clock" to be checked (visualisation on plans - third party)		15. Metric for daily work completion	16. Metric for quality
	2. Process planning tool (further development in practice by third party)								10.Logistic cards	12.Material database linked to LCM (third party development)	14.Visualisation of constraint on actionplan in LCM area			
	3. Overall process analysis action list									Further links to BIM (in development in practice by third party)				
	4. Process planning action list													
	Original development						Models: 1,3,4,6,7,8,11,13,14,15,16							
	Further development in practice by third parties						Models: 2,5,9,10,12							

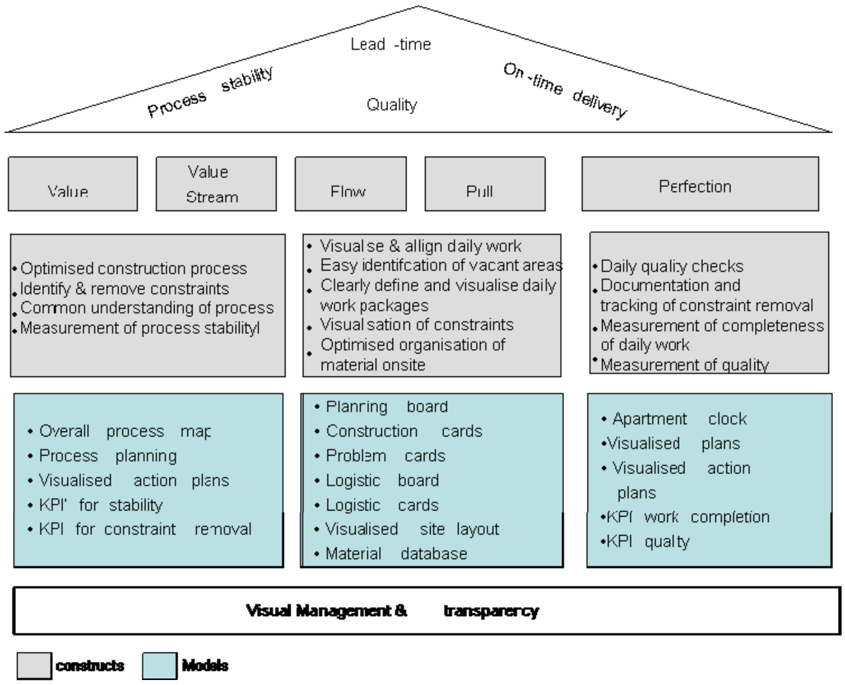

Figure 2: Illustration of constructs and models within LCM implementation

Table 3: LCM Method

		METHOD
MODEL	1	a) Process mapping (visualisation) of entire construction processes carried out by lean specialist together with construction specialists involved in project. Carried out once at the very beginning, as early as possible before construction commences b) Identification of critical interdependencies and constraints c) Definition of optimal flow
	2	a) 4- month detailed overview of constructon work, including milestones, constraints b) Carried out 2-4 times per month by lean specialist or foreman together with planers and company representatives c) Proposal sent in advance for preparation to companies d) Identification of constraints and actions for removal
	3	a) Exists once at the very beginning b) Visualised in LCM area until all actions are completed c) Implementation status visualised with metic % completion
	4	a) Updated at each PP session b) Visualised in LCM area c) Implementation status visualised with metic % completion
	5	a) Updated after each process planning
	6	a) Construction cards prepared and visualised daily by companies b) Basis for weekly planning meeting onsite in LCM area c) Monitored and controlled by foreman
	7	a) To be filled in daily by construction company representatives and placed on board
	8	a) Constraints identifed by construction workers / companies and visualised on cards. Then placed on board.
	9	a) Logistic cards to be placed on board on weekly basis by companies
	10	a) Description of what resource is needed by company on logistic card. All details must be filled in - company, resource (ie container, crane..), date, time etc..
	11	a) Suppliers use this for site orientation and to see what slot has be allocated for their material
	12	a) Data to be retrieved by foreman from companies
	13	a) Construction worker displays card on green side on apartment clock or on plan in LCM area b) Foreman checks completed green card for quality on daily basis c) If quality ok, the card is placed green side up on the board. If not, it is turned back around, improved action is defined and communicated and visualised on clock or LCM area.
	14	a) Actions to be defined by foreman together with companies and visualised in LCM area
	15	a) Forman measure daily competion of planned cards and visualies result
	16	a) Forman measure daily competion of planned cards and visualies result

EVALUATION CRITERIA

The section above describes the constructs, models and methods of LCM. The application of these models together in the specified way (method) represents an instantiation. Building the first of virtually any set of constructs, model, method, or instantiation is deemed to be design science research, provided the artefact has utility for an important task. The research contribution lies in the novelty of the artefact and in the persuasiveness of the claims that it is effective. As mentioned earlier, the LCM method is evaluated both internally and externally based on examples on a number of instantiations. In design science, when evaluating an artefact, often the question is simply, does it work? A number of important criteria to be considered when evaluating an artefact using the design science approach are mentioned above. For example, according to March & Smith et al, 1997, research in the build activity should be judged based on value or utility to a community of users. In the case of LCM, these users are of two types: construction project personnel and academics. It is important to access this utility based on both its practical and theoretical contribution. Van Aken, 2004 refers to evaluating the effectiveness of a certain rule in the original context (α-testing), while Lukka (2000) emphasises the need to "ponder the scope of applicability of the solution" or translating the rule to other contexts. Lukka (2002) also emphasises the need for the researcher to explicate the theoretical contribution of the artefact during the evaluation by reflecting the findings back to prior theory. From these ideas, high level criteria have been identified as basis for the evaluation framework. They are: usefulness, applicability and theoretical importance. Figure 4 (a) and (b) shows the overall evaluation framework to be used in evaluating each of the models of LCM and the method as a whole. Evaluation questions have been defined to apply to each of the individual components and the overall LCM instantiation. For example, do the models and methods improve the daily planning of activities onsite? Do they help in the identification and removal of constraints? Do they contribute to the identification and removal of waste? Are they useful in improving transparency in the overall process? Has communication been improved and a good level of common understanding achieved? Shingo and Ohno (Shingo 1992) identified seven different types of manufacturing wastes that can also be found in construction: overproduction, waiting time, transport, inventory, motion, defects and processing. Koskela identified making-do and Macomber & Howell (identified failure to communicate as further wastes in construction. Can the effectiveness of the instantiation be measured? In the literature, the importance of metrics as part of a lean culture is emphasised. Accessible metrics that drive lean behaviour represent a significant opportunity for increasing transparency and managing accountability. An important part of the evaluation is to validate the usefulness of all models within the LCM method using clearly defined metrics where possible. With regard to applicability, can the models be easily adapted to other project types? Is it easy to use? A further high level criteria is focused on the identification and analysis of the theoretical contribution (Lukka, 2000). According to Lukka, 2000, the researcher has to be able to explicate the theoretical contribution of the artefact by reflecting the findings back to prior theory. Here it should be specified what the contributions are: ie, a) the novel construction itself, b) development of a new theory, refinement of an existing one, illustration of an application of an existing one (e.g. the analysis of LCM in terms of Womacks five principles"). Henver et al (2004) emphasises the importance of the clear identification of a contribution to the archival knowledge base of foundations and methodologies as a key differentiator between routine design and design research.

LCM MODEL									
		1. Overall process map	2. Process planning tool	3. Overall process planning action list	4. Process planning action list	5. Stability metric	6. Planning board	7. Construction cards	8. Problem cards
1.USEFULNESS	Daily planning	Q.1 Did these model improve daily planning of activities and / or site logistics and if so, how?							
	Constraint removal	Q. 2 Could contraints be identified, removed and monitored using these models?							
	Waste	Q. 3 Did the use of these models lead to the identification and removal of waste?							
	Transparency	Q. 4 Was communication and a better common understanding achieved? Could information be easily accessed?							
	Measureability	Q. 5 Was is possibile to measure improvements? ie number and types of constraints, improvements implemented, stability of promises.							
2.APPLICABILITY	Adaptability	Q. 6 Can these models be adapted to different types of projects?							
3.IMPORTANCE	Theoretical contribution	Q.7 How do the LCM models contribute to theory? Q.8 How different is it from previously used systems? Q.9 What new ideas does it contribute to the body of Lean Construction literature?							
		further development in practice by third parties							
		original development							

Figure 4(a) Evaluation framework for the LCM models 1-8

LCM MODEL									
		9. Logistic board	10. Logistic cards	11. Visualised colour-coded site layout	12. Material database linked to LCM	13. Complete cards visualised on "apartment clock" (now on plans).	14.Visualised action plan in LCM area	15. Metric for daily work completion	16. Metric for quality
1.USEFULNESS	Daily planning	Q.1 Did these models improve daily planning of activities and / or site logistics and if so, how?							
	Constraint removal	Q. 2 Could contraints be identified, removed and monitored using these models?							
	Waste	Q. 3 Did the use of these models lead to the identification and removal of waste?							
	Transparency	Q. 4 Was communication and a better common understanding achieved? Could information be easily accessed?							
	Measureability	Q. 5 Was is possibile to measure improvements? ie number and types of constraints, improvements implemented, stability of promises.							
2.APPLICABILITY	Adaptability	Q. 6 Can these models be adapted to different types of projects?							
3.IMPORTANCE	Theoretical contribution	Q.7 How do the LCM models contribute to theory? Q.8 How different is it from previously used systems? Q.9 What new ideas does it contribute to the body of Lean Construction literature?							
		further development in practice by third parties							
		original development							

Figure 4(b) Evaluation framework for the LCM models 9-16

CONCLUSIONS

The evaluation framework presented in this paper will be applied to the individual models of LCM and the LCM method itself. The main focus of the evaluation is to determine whether LCM has been effective in achieving measurable improvements onsite, how applicable it is across a variety of projects and how it contributes to the body of Lean Construction literature. The next steps of the research will be to describe the LCM instantiations and apply the framework.

REFERENCES

Da Rocha, C., Formoso, C., Fazenda, P., Koskela, L. & Tezel, A. (2012), "Design Science Research in Lean Construction: Process and Outcomes", *In IGLC-20 proceedings*, San Diego, USA.

Espana, F., Tsao, C. & Hauser, M. (2012). Driving continuous improvement by developing and leveraging lean key performance indicators. IGLC proceedings, 2012.

Hevner, A. R., March, S. T., Park, J. and Ram, S. (2004). “Design science in information systems research.” *MIS Quarterly*, 28 (1) 75-105.

Hull, R. and King R. (1987), Semantic Database Modelling: Survey, Applications and Research Issues, ACM Computing Surveys, Vol. 19, No. 3, Sept. 1987, pp. 201-260.

Koskela (1992). application of the new production philosophy to construction, centre for integrated facility engineering, Technical report # 72

Kraemer, K. and King, J. (1998) Computer-Based Systems for Cooperative Work and Group Decision Making, ACM Computing Surveys, vol 20, no 2, June 1988, pp 115-146.

Lukka, K. (2000) The Key Issues of Applying the Constructive Approach to Field Research. In Reponen, T. (ed.) (2000) *Management Expertise for the New Millenium*. In Commemoration of the 50th Anniversary of the Turku School of Economics and Business Administration. Publications of the Turku School of Economics and Business Administration, A-1:2000, p.113-128.

Lukka, K. (2003). The constructive research approach. In Ojala, L. & Hilmola, O-P (eds.). Case study research in logistics. Publications of the Turku School of Economics and Business Administration, Serier B1: 2003, p.83-101

Macomber, H. & Howell, G (2004) 'Two Great Wastes in Organizations: a typology for addressing the concerns for the underutilisation of human potential,' in proceedings IGLC12, LO-School, Elsinor, 25-27 July.

March, S. T. and Smith, G. F. (1995) “Design and natural science research on information technology.” Decision Support Systems, 15 251-266.

Nolan, R. (1973), Managing the Computer Resources: A Stage Hypothesis, Communications of the ACM, vol 16, no 7, July 1973, pp 399-405.

Pekuri, A., Herrala, M., Aapaoja, A. & Haapasalo, H. (2012). Applying Lean in Construction – cornerstones for implementation. IGLC proceedings, 2012.

Picchi, F. A. and Granja, A. D. (2004). "Construction Sites: Using Lean Principles to Seek Broader Implementations.” In IGLC-12 proceedings, Copenhagen, Denmark

Pfeffers , K., Tuuanen, T. & Rothenberger, M.A. (2007), A Design Science Research Methodology for Information systems Research. Journal of Management Information Systems

Schön, D. A. (1983). The Reflective Practitioner. London: Temple Smith.

Shingo, S., 1992, The Shingo Prize Production Management System: Improving Process Functions (Cambridge, MA: Productivity Press).

Vaishnavi, V.K; Kuechler, W.Jr. (2007) “Design Science Research Methods and Patterns Innovating Information and Communication Technology.” Taylor & Francis Group, 244p, chapter 2

Van Strien, P. J. (1997). ‘Towards a methodology of psychological practice, the regulative cycle’. Theory and Psychology, 7, 5, 683–700.

Womack, J.P. & Jones, D.T. (1996). “Lean Thinking: Banish waste and create wealth in your corporation”. Simon & Schuster.